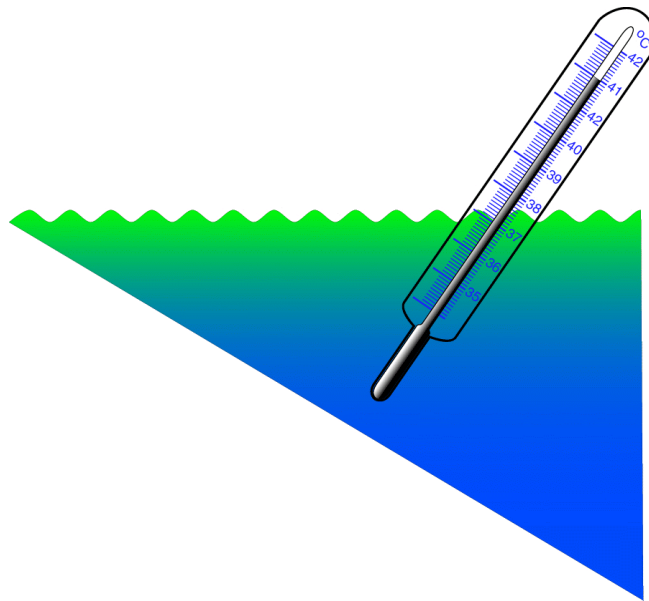


Consequences of weather and climate changes for marine and freshwater ecosystems

Conceptual and operational forecasting of the aquatic environment



A 4 year research programme proposed by professor Morten Søndergaard, University of Copenhagen on behalf of a consortium comprised of:

Freshwater Biological Laboratory, University of Copenhagen (FBL)
Danish Climate Centre, Danish Meteorological Institute (DMI),
DHI-Water & Environment (DHI),
National Environmental Research Institute, Dept. of Lakes and Estuaries (NERI),
The Danish Institute for Fisheries Research (DFU),
Department of Marine Ecology, Aarhus University (AU)
Institute of Geography, University of Copenhagen (GI),
Geographical Resource Analysis & Science A/S (GRAS),
Department of History and Civilisation, Southern Denmark University (SDU).
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This proposal focuses on developing a fundamental scientific understanding of the interactions between weather/climate¹ and the physical, biogeochemical and biological processes that define the state of aquatic environments found in and around Denmark.

Background

Changes in the environmental status of fresh and marine waters have been observed in Denmark and elsewhere during recent decades and considerable research has been directed towards elucidating the impact of human activities (e.g. eutrophication, exploitation) on these aquatic ecosystems. It is recognised that weather/climate also affects the productivity and the state of aquatic ecosystems and that any anthropogenic influence on these systems is occurring against background fluctuations mediated by climate. However, little effort has been directed to quantify and predict the influences of weather-modulated impacts on aquatic ecosystems.

¹In the present study the time perspective is at decadal and centennial scales and the term weather/climate covers both periods with climate defined as the average of key meteorological variables over 30 years.

Such a predictive capability becomes particularly relevant seen in the light of expected significant climate changes in the coming decades (IPCC 2001). There is some uncertainty with respect to the magnitude and for some quantities even the direction of expected change due to incomplete understanding of the factors forcing global circulation patterns (e.g. Hansen et al. 2001). Climatic conditions vary on annual to centennial scales also at the regional level. Observations indicate that significant changes in the global and regional climate have occurred over the last century (IPCC 2001). Moreover, projections based on climate models suggest that even larger changes may occur during the next century (IPCC 2001). The anticipated climate changes for Denmark suggest generally warmer and wetter conditions, with some increase in the frequency of storms and heavy precipitation events (Kaas & Andersen 2000, Christensen & Christensen 2001, Machenhauer et al. 1998).

We anticipate that the regional climate changes will lead to changes in: (1) the transport of matter from land to sea, (2) the turnover of nutrients and organic matter, (3) the water column stability in lakes, estuaries and marine areas, and (4) the trophic structure and dynamics of these systems. These changes will, in turn, influence the state of aquatic ecosystems and their potential for recreational and economic (i.e. through harvest of organisms and other resources) exploitation by human societies. Only with a concerted interdisciplinary research effort will it be possible to begin predicting the important effects of climate variability on the productivity, the trophic structure and environmental state of aquatic ecosystems.

Research visions and objectives

Our vision is to quantify the influence of climate on the state of marine and freshwater ecosystems and to produce a "water forecast". The aim is to become able to predict the effects on the water quality and the ecological state of different regional water bodies on a decadal to centennial scale. This aim is motivated by climate change simulations, which indicate significant changes toward the end of this century (e.g. Jørgensen et al. 2001).

We propose a programme that will:

- ? develop a conceptual understanding of how the present and future climate will interact with fundamental ecological processes in aquatic systems ranging from streams and lakes to coastal areas and more open seas
- ? translate and develop this information to operational models with the perspective to

quantify effects of climate change over short (decades) and long time scales (centuries)

The programme has the following content:

- ? analysis of available historical and palaeolimnological data for possible climatic influences on nutrients and biological structure. Special focus will be on marine and freshwater fish communities and the linkage to fisheries
- ? investigation of the effects of climate related changes in runoff and land use and the transport, turnover, retention and sedimentation of nutrients and fine-grained material from land to sea
- ? quantification of the controlling role of temperature and its interaction with nutrients for biological structures and processes in streams, lakes and marine areas
- ? development of predictive models relating water column structure and the transport of nutrients and sediments to changes in local and regional climate
- ? development of empirical and dynamic models describing the chemical, biological and sedimentological consequences of changes in the water column stability of stratified lakes and marine areas
- ? assess the possible consequences of future climate-induced changes for Danish aquatic ecosystems with regard to management strategies

The coordinated effort within this “end-to-end” project will enable an unprecedented quantification of possible future climate changes, their impacts and the associated uncertainties for aquatic systems.

The project and the “STF” intentions

The Consortium includes scientists with the necessary expertise (atmospheric sciences, hydraulic modelling, biological and physical oceanography, transport and sedimentation processes, functional biology of marine and freshwaters, environmental analyses, palaeolimnology and the use of historical records, see Appendices 2 and 3) to carry out the proposed research programme. By Danish standards, it is a large and diverse group of researchers, from a wide range of institutions, who are committing themselves to work together for a common goal in a new and formal partnership.

Most of the researchers in the Consortium have previously contributed to the international literature with new knowledge concerning specific aspects of climatic influence on aquatic ecosystems. However, never before in Denmark (or, to our knowledge,

elsewhere) has such a diverse group of scientists joined together with the goal of predicting climate effects on the water quality and ecological state of different water bodies on a decadal to centennial scale. We believe that we are uniquely placed in Denmark with respect to achieving such a goal. Aquatic, atmospheric and sedimentological/hydrological sciences in Denmark are all recognised internationally. In addition, in Denmark many unique time-series and historical records exist that provide the potential of relating relevant biological, sedimentological and physical data to climate change throughout time.

Having a multi-disciplinary research group is a necessary but not a sufficient prerequisite for carrying out truly interdisciplinary research. It further requires a real interaction between the disciplines and it is often these areas of interaction that prove to be most fertile for scientific advances. In order to stimulate interdisciplinarity, the following strategy has been developed:

- six workpackages (WP) have specifically been designed to address cross-disciplinary scientific questions
- the leading partner for each WP has the responsibility of developing cooperation and coherence without losing scientific depth and quality
- most of the anticipated Ph.D. projects and postdoc positions will be defined in areas of disciplinary interfaces in order to promote cooperation and exchange of ideas between scientists from differing disciplines
- the project leader will use a Steering Committee and an External Advisory Board to ensure overall project coherence
- emphasis will be given to the production of interdisciplinary, multi-author publications
- partners are required to make their knowledge and expertise available for other partners in the Consortium

International relationships

The proposed project complements, but does not duplicate, several ongoing major international and global programmes including several core projects under the International Geosphere Biosphere Program (www.igbp.kva.se); for example Global Ocean Ecosystem Dynamics (www.pml.ac.uk/globec/) focusing on how climate affects fish populations and marine ecosystems and Limpacs (www.geog.ucl.ac.uk/ecrc/limpac) dealing with cross-comparisons of long-

term contemporary data-series and palaeoecological records with the objective to improve forecasting of various human impacts and climate on lake ecosystems from improved hind-casts and modelling. One researcher in the Consortium is on the Scientific Steering Committee of IGBP, two are active in GLOBEC initiatives and two are active in and on the steering committee for Limpacs. The project also complements the international research initiative “History of Marine Animal Populations” (www.core.ssc.erc.msstate.edu/censhmap1.), where, again, researchers in this Consortium are active. Several of the partners carry out complementary, but not redundant, research in several EU projects, among these DOMAINE (www.domaine.ku.dk) and CLIMFRESH (www.fblzi.ku.dk/climfresh) studying the effects of dissolved organic matter in coastal seas and the impact of increasing atmospheric CO₂ on freshwater plants, respectively, LIFEKO (www.lifeco.dk), with the aim to study plankton productivity in marine frontal zones, PRUDENCE, with the aim to quantify uncertainties on European climate change calculations and PIONEER (www.pioneer.georg.ku.dk) concerned with the day to day forecast of nutrient and sediment concentrations in estuaries.

Project organisation and management

As requested, this information is found in Appendix 2. A brief managerial plan of workshops and evaluation meetings is included in Table 1.

Dissemination strategy

The dissemination of results shall occur via five, not totally exclusive, routes: (1) most results are planned to be published in international peer-reviewed journals, (2) as the research focus is on national water bodies it is our commitment to present the key results in local “popular” journals, (3) a “public window” with access to results and general information will be available as a professional and frequently updated home-page edited and maintained by GRAS in cooperation with the project leader, (4) the important contact between NERI and all Danish counties and other environmental agencies and between DFU, Danish fishery organisations and ICES will be used to disseminate key results at regular meetings among these parties, and finally (5) we plan to conclude the project with a national conference, possibly with a strong media profile and to produce a book with the most relevant results (see Workpackage 6).

Educational aspects

It is foreseen that an interdisciplinary research group bridging Danish basic and applied environmental research offers an attractive and exciting educational opportunity for a large number of Master students (about 40). Further, 7 Ph.D. students and 7 to 10 postdocs are working under the umbrella of the proposed project. To strengthen the interdisciplinary education, it is proposed that most of the students and postdocs work at the interface between several or at least two disciplines and to be advised by senior researchers from at least two institutions, including, at least one university. Thus, the project should be able to train and educate a number of young academics and researchers with an interdisciplinary outlook, which should make them attractive for employers.

Research plan

Research strategy and methodology

The programme employs a multi-pronged research strategy built on three key elements:

- development of empirical relationships from historical records/observations, palaeolimnological data and climate/weather time-series
- key ecological processes influenced by climate are targeted through observations and experiments
- development of climate and ecosystem models generated by linking and improving existing climate, marine and limnological models to test hypotheses and provide operational prognoses

One first task is to recover and analyse parameters describing aquatic ecosystems from historical records and palaeolimnological data available at a centennial time scale and observational time-series available for the past 20 to 100 years. These parameters are compared with climate and weather time-series to develop conceptually based empirical relationships of climate interactions and aquatic ecosystems. The high quality Danish meteorological observations, the North Atlantic Oscillation Index (NAO), tree rings and ice coverage are used as indicators to probe climate variability. The former two will be related to measured runoff, transportation of nutrients and matter in streams and the detailed time-series of ecological observations and measurements available for Danish streams, lakes and marine areas. Further, NAO and tree rings are used as climatic proxies to analyse historical and palaeolimnological data. These activities will lead to hindcast modelling of the effects of climate/weather forcing on key hydrological, sedimentological and ecological processes as well as

biological structure.

Establishing causality for the climate forced empirical relationships will be attempted by identification of key processes targeted through observations and laboratory and field experiments. The latter will be carried out as very large scaled mesocosm experiments. These activities will allow the development of improved conceptual impact models, empirical models and algorithms for dynamic modelling. These, in turn, will be used to develop and improve the nowcast description of the state of different aquatic systems, e.g. Danish seas by the marine impact model FARVANDSMODEL developed by DHI-Water & Environment (Edelvang et al. 2001). In addition, the existing regional climate model (HIRHAM) developed by the Danish Climate Centre (Christensen et al. 1996) will be improved and validated through the activities and used to construct relevant future climate scenarios geographically scaled both for freshwater bodies and Danish marine areas. These future climate scenarios will be used as input to the marine impact model and the other ecological and runoff models resulting in quantitative and conceptual prognoses for the future state of Danish aquatic systems. Finally, the results will be assessed for possible consequences for future management strategies with respect to different types of aquatic systems.

While our research plan is ambitious and comprehensive and will provide an understanding of climate forcing of a variety of aquatic ecosystems, it is necessary to limit the scope of the project. Groundwater processes, for instance, are intimately linked with surface water runoff and transportation of matter. The focus of the proposed research programme is on surface waters and groundwater will not be considered in any detail. Likewise, the research programme as a starting point only employ boundary conditions to the regional climate simulations from one data set of a coupled atmosphere-ocean general circulation model (Stendel et al. 2000).

The research will be organised in six Workpackages (WP) composed of several specific activities (Table 1). Fig.1 indicates the complexity of the proposed programme, both scientifically and managerially, and summarises (1) the interactions between climate and aquatic ecosystems, (2) how the organisation of the research interlinks different ecosystems and catalyses cooperation among partners and finally (3) how the results from the different workpackages will feed the prognoses to be developed in WP5. The involvement of each partner in the activities is outlined in Table 1 and Fig. 1.

Research focus and hypotheses

Streams, lakes, estuaries and regional marine areas will largely be exposed to similar climate changes, but, due to specific physical and biological characteristics they are expected to react differently.

The effects of climate on seasonal river discharge vary across Europe (Arnell 1999). In Denmark, the predicted climate change tends to expand the range in discharge, but not to alter its timing. Winter flows tend to increase and summer flows are generally reduced (Arnell 2000). During the 20th century, significant upward trends in the annual mean discharge in rivers in the western part of Denmark were detected. The past and possible future changes in discharge will have strong impacts on the mobilisation, transport and retention of organic matter, sediment and nutrients in streams, lakes, wetlands, floodplains and coastal waters (Kronvang et al. 1999).

Because soils are a major reservoir in the terrestrial carbon and nutrient cycle, changes in organic matter content and erosion due to climate change can seriously impact groundwater, freshwater and estuarine systems. It is likely that the effect, in general, will be to reduce soil organic carbon content through increased temperature and increased mineralisation (Kirchbaum et al. 1996). Such changes can modify the soil's water holding capacity and its physico-chemical properties which, in turn, can influence soil erosion. Moreover, soils are important in regulating the storage and release of nutrients (nitrogen and phosphorus) and agrochemicals (pesticides and heavy metals). An increase in mineralisation and soil erosion due to climate change can thus increase the transfer of these substances from land to water and, hence, deteriorate the quality of surface waters. The highly eutrophied Danish aquatic ecosystems surrounded by intensively farmed land with high content of nitrogen, phosphorus and agrochemicals will be especially vulnerable to climate change through enhanced transfer rates from land to water. Therefore, one core task is to establish a very detailed hindcast and nowcast modelling of known climate forcing, runoff data and archival sedimentation records.

We anticipate that the impact of climate changes will be stronger in smaller than in larger catchments where downstream changes in groundwater storage and retention capacity of the river-floodplain system will prolong the response time from the upper part of the river systems towards the estuarine zone. The predicted increase in average temperature will result

in increased temperature in springs and small groundwater fed streams while larger rivers will show greater seasonal fluctuations. Such changes are expected to have consequences for the biota in streams.

The estuary is the region where river water is mixed with sea water by tidal action, waves and density circulation. In Denmark, estuaries are represented by the Wadden Sea influenced by tides and Danish fjords dominated by wave mixing of fresh water and salt water. The discharge may have high contents of nutrients and organic matter with a profound impact on primary production and sedimentation in the coastal region. One river end-member is the Wadden Sea lagoon, western Jutland. Here the sediment stability in mudflat regions is controlled by algae and sediment dwelling organisms. Because these areas are prone to both changes in input of matter and nutrients and to light and temperature conditions during exposure (Andersen & Pejrup 2001), it is predicted that intertidal mudflats will be particularly sensitive to climate change. In the same way, changes in discharge will first impact the estuarine systems, which may delay and buffer the impacts of terrestrial weather/climate changes in marine areas caused by discharge.

The majority of lakes in Denmark are shallow and their environmental state (turbid or clear water) is controlled by the coupled effect of nutrient loading and biological structure (Jeppesen et al. 2000). Both nutrient loading and biota are impacted by climate forcing at seasonal and annual scales. However, current lake research focuses on nutrients and biological structure and the consequences of climate-forced variability for both shallow and deep lakes are not well understood. The proposed research in lakes will therefore focus on the interactions between climate, nutrients, water stratification and biota and will develop conceptual and quantitative models capable of making environmental prognoses of future climate scenarios.

Her sidder Table 1 og Fig. 1 på hver deres hele side.

The critical variables for the environmental state of shallow lakes under the predicted conditions of regional climate change are temperature and wind-induced resuspension of sediments. Higher average temperature results in reduced probability of ice cover, higher mineralisation rates, enhanced winter survival of large-bodied zooplankton and submerged macrophytes and earlier hatching of the fry of piscivorous fish (George et al. 1990, Mehner et al. 2000, Benndorf et al. 2001). While better survival of macrophytes, larger zooplankton and piscivorous fish due to positive feed-back mechanisms reduces the risk of algal blooms in spring (Scheffer et al. 1993, Moss 1998) a higher input of nutrients via more frequent resuspension events and warmer summers may favour algal growth. Thus, there is a risk (probability) that the future regional climate triggers shallow clearwater lakes to shift to a turbid state. However, it is unknown which of the opposing factors, grazing, predation or nutrient loading is the stronger. Cyprinid fish species are controlling the environmental state in shallow and very eutrophic lakes Jeppesen et al. 2000). Thus, the reduced probability of winter fish kills due to ice cover and resuspension events (Hamilton & Mitchell 1996) may act counterproductive for the efforts (biomanipulation and reduced loading) to change turbid lakes to clearwater lakes. In addition, invasive planktivorous and benthivorous fish species (e.g. carp) from warmer regions may be anticipated to colonise Danish lakes. Predicted climate change thus might have very complex biotic and abiotic interactions that are difficult to forecast. Analyses of available, historical fish records observational time-series and palaeolimnological data (Anderson & Odgaard 1994, Jeppesen et al. 2001) and exploitation of high quality monitoring data (Jeppesen et al. 2000, Sand-Jensen et al. 2000) will help to develop a capability for future environmental prognoses for shallow lakes. These approaches will be complemented with a large investment of money and manpower in experimental studies which will investigate the physical and ecological impacts of increased temperatures.

Deep lakes are stratified during summer and their general ecology is in addition to nutrients strongly influenced by circulation depth and duration of stratification. The predicted higher average temperature during spring and autumn may lengthen the stratification period, which in nutrient rich Danish lakes may enhance the risk of oxygen depletion in the bottom water (hypolimnion), leading to higher phosphorous release from the sediment, and change the biomass, composition and distribution of phytoplankton in time and space. In turn, the phytoplankton biomass absorb light. Thus,

phytoplankton is not only controlled by the stratification pattern but partly controls the light climate and thereby provide a feed-back on stratification (Snucins & Gunn 2000). To understand and model the physical, chemical and biological environment in deep lakes it is a prerequisite to establish a stronghold in physical limnology. The downscaling of the regional climate model (HIRHAM) to a relevant lake size and the availability of monitoring data for deep lakes are important tools in the development of physical and biological models, which are necessary for reliable climate impact prognoses.

Like deep lakes the structure and function of shelf seas surrounding Denmark are closely linked to climatic forcing through solar radiation, winds, waves, turbulence, the transport of nutrients and sediments and, additionally, freshwater discharge. Predicted climate change will affect the hydrographic conditions with ecological consequences including changes in primary production (Richardson et al. 1998), the distribution of marine organisms (e.g. Kiørboe 1992, Edelvang et al. 2001, MacKenzie & Visser 2001), and the distribution and frequency of hypoxia and anoxia (Hansen et al, 1995). These changes will influence human exploitation and recreational activities in coastal seas. However, quantification of the climatic influence on human interactions with marine resources has never been attained. A changing climate could alter the geographic range of fish species and fish populations with distributional limits in or close to Danish waters (e.g. cod, herring, sole, blue-fin tuna). As the actual distribution of many species will lag behind environmental changes, historical fish records may be useful for testing possible linkages of fish distribution and abundance to major climatological factors and hydrographic changes (Holm 1996, Alheit & Hagen 1997). This research approach will be employed in the programme.

Concurrently with the development of empirical relationships between climate and various states of marine ecosystems, the proposed research programme will examine the mechanisms leading to these relationships. The most obvious physical-chemical impact anticipated for Danish marine waters as a consequence of predicted climate change is changes in water column stability, temperature and nutrient availability.

Global climate change scenarios (e.g. Bopp et al., 2001) indicate that increased stratification of global oceans resulting from global warming will lead to an overall reduction in primary (export) production of about 6% and even greater reductions in tropical and

temperate regions. While such models provide qualitative predictions for global oceanic conditions, it is unclear to what extent these generalisations can be applied to the relatively shallow seas surrounding Denmark. Will the predicted increase in stratification owing to warming and increased precipitation, for example, be overwhelmed by increased mixing due to an increased frequency of storm events? Accordingly, a key focus of this programme is to examine how climate change will affect the physical conditions of the marine environment at the regional scale.

Stratification influences both the magnitude and the seasonal distribution of primary production. Most Danish marine waters are stratified during summer and autumn so that productivity and problems with anoxia are tightly linked with hydrographic conditions, nutrient supply and mixing (Richardson & Jørgensen 1996). In recent years it has become obvious that phytoplankton blooms occur throughout the period of stratification in all Danish waters (e.g. Richardson et al. 1998). The duration and depth of stratification and the hydrographic processes occurring at the mixing interface control the magnitude and timing of the primary production (Richardson & Pedersen 1998). Further, wind-induced mixing events control the production in surface waters. Thus, any changes in the duration or characteristics of stratification will potentially change the magnitude and/or the seasonal distribution of primary production. Another focus of this programme will be to examine the effect of changes in stratification on primary production in various regions and how possible future changes in sediment fluxes and deposition from terrestrial sources will influence the nutrient supply from Danish streams and their regeneration in the sea bed and water column. One important tool for this analysis is the climate scenarios generated by the HIRHAM model driving the hydraulic impact model FARVANDSMODEL. The results of the prognoses will point to possible future changes in the marine ecosystem on a decadal scale and thus enable suggestions for management strategies to be evolved.

Temperature is an important factor in controlling the geographic range of marine organisms and community processes are also affected. Community respiration and bacterial activity have been found to increase more than primary production when temperature increases (Pomeroy & Wiebe 1993, Christian & Karl 1995) and warmer temperature may be followed by changes in the composition of phytoplankton (Rae & Wincent 1998). The influence of temperatures and nutrient availability on

community structure and balance between autotrophic and heterotrophic processes are therefore important environmental variables to study in a climate change perspective.

The focal working hypotheses in the predicted future regional climate are:

- ? climate change will counteract the positive effects of the ongoing efforts to reduce the nutrient loading of surface waters
- ? higher transport of sediments, nutrients and organic matter from land to streams, lakes and the sea
- ? that Danish streams might lose or be impoverished with respect to their cold-water flora and fauna
- ? changes in the composition and abundance of plant species in streams by the coupled effects of temperature and nutrients
- ? enhanced eutrophication in nutrient-enriched shallow lakes and a less predictable response at intermediate nutrient level as the reaction depends on partly counterbalancing factors
- ? that biotic changes occurring during increasing winter temperature have major cascading effects the following summer
- ? changes in temperature, mixing, and nutrients will favour eutrophic phytoplankton species in lakes and marine areas
- ? increased risk of dominance and prolonged blooming of (toxic) cyanobacteria in lakes due to higher temperature, higher phosphorous and more stable water column
- ? changes in temperature and light conditions will change the ecological balance between algae and other organisms and impact the stability of intertidal mudflats
- ? that climate-induced variability has influenced fish landings in Denmark at decadal scales during the last 5 centuries, partly because of distributional shifts in species throughout the North Sea
- ? the importance of subsurface plankton production will increase with respect to the spring bloom in important fisheries region in the North Sea and favour pelagic rather than demersal fishes
- ? that multiple small phytoplankton blooms repeatedly interrupted by storm events have a sedimentation pattern different from the classical 'one-event' spring bloom
- ? the predicted future increase in average annual temperature is acting in concert with increased nutrient loading and will affect the structure and

function of marine and freshwater communities

Workpackages

To investigate and test the hypotheses and to accomplish the stated objectives, the proposed work is organised in six workpackages (WP) composed of activities. Below is a short description of each WP and identification of the WP leader and participating institutions. The Activity-titles are found in Table 1 and details on deliverables are presented in Appendix 6.

Workpackage 1

Establishing empirical relationships between climate and long-term dynamics of aquatic ecosystems

Leader: DFU. *Participating institutions:* SDU, NERI, FBL, GI, DMI. *Subcontractor:* GEUS.

The workpackage will analyse direct and indirect indicators of changes in plankton food web structure, fish production and fishing activity in relation to climate variability. The direct indicators of aquatic ecosystem state will be derived from long-term monitoring studies of lakes and from historical records of fish landings and fishing activity in Denmark and other North Sea countries. Data from 37 Danish lakes followed intensively since 1989 and a 300-500 year fish catch record will be used. The indirect evidence of ecosystem state will be derived from palaeolimnological analyses of micro- and macrofossils in Danish lakes by using existing sediment core data from > 30 lakes. The climate will be exemplified by NAO, tree rings and by measured climate data.

The objectives are to:

- examine the decadal to century scale variability in aquatic secondary production and the distribution of fish species and other biota in aquatic ecosystems in relation to climate variability
- test hypotheses of the interrelationship of biota, climate and other anthropogenic impacts (e.g. fishing and eutrophication) at these long time scales and with a regional approach

Workpackage 2:

Hind- and forecasts of weather-induced changes in hydrology, sediment and nutrient transfer in the interconnected stream, lake and estuarine systems

Leader: GI. *Participating institutions:* NERI, DHI, DMI

The workpackage will analyse existing national data

on discharge and transport of nutrients and sediments from source (stream) to sink (the estuarine zone and the sea) and relate these to known regional weather data in order to achieve hindcast and nowcast modelling of the climatic forcing on leaching, soil erosion and sediment nutrient transport and deposition from stream to sea. Dating of sediment cores will be used to estimate sources and sinks of nutrients in lakes. For this purpose we have at hand daily discharge data from 25 catchments over 83 years, sediment cores from > 30 lakes and detailed meteorological data for 100 years. The analyses will disclose regional runoff gradients and with the improved spatial resolution of the regional climate model make it possible to forecast the impacts of climate change on the hydrological regime, sediment and nutrient dynamics in streams and lakes during the 21st century. The estuary with the high productive zone of intertidal mudflats and the morphological stability of coastal salt marshes will be specifically addressed.

The objectives are to:

- ? analyse and model decadal variability in runoff and sedimentation and relate these data to climate variability
- ? develop models to predict the impact of future climate scenarios on the transport of matter and nutrients from source to sink
- ? evaluate future stability of coastal lagoons and salt marshes

Workpackage 3

Coupling between physical forcing and ecology

Leader: DMI. *Participating institutions:* DHI, DMU, DFU, AU, FBL, GRAS

This workpackage seeks to define the linkage between climate (physical forcing), physical conditions of marine and freshwater environments, and the subsequent ecological impacts on these ecosystems. A regional approach with the climate model (HIRHAM) will be adapted towards obtaining this goal. The climate model will for this purpose interact with the marine impact model ("FARVANDSMODEL"), be down-scaled to a relevant lake size and then used to analyse for climate-components in the existing limnological observations covering 12-17 years and 15 summer-stratified lakes

The objectives are to:

- simulate marine nowcast scenarios with the "FARVANDSMODEL" based on present-day HIRHAM climate parameters, fluxes of water and sediment and physical and biological parameters.

Simulations will be performed for several set-up conditions

- verify marine simulations against satellite images and improve the HIRHAM model by feedback
- improve and verify the biological equations of the “FARVANDSMODEL” in the light of observations and process oriented models (WP 2 and 4)
- develop empirical and improve existing dynamic models for water column stability of seasonally and permanently summer-stratified lakes and marine areas and the derived consequences for nutrient dynamics and biological structure
- develop a process based physical-biological model to investigate the dynamics of subsurface fronts and associated primary production and food webs

Workpackage 4

Influence of temperature and nutrients on biological structures and processes: an experimental approach

Leader: NERI. *Participating institutions:* AU, FBL, DFU and DHI

This workpackage covers a number of experiments focusing on the impact of changing temperatures on trophic structure and dynamics and nutrient cycling in streams, lakes and marine areas. The most pronounced climate changes are predicted during winter. It is hypothesised that these changes will have cascading effects on the structure and function of the food web during summer. A multi-faceted approach ranging from small-scale laboratory experiments to *in situ* enclosure studies at different temperatures and intensive *in situ* measurements under natural winter conditions will be used.

The objectives are to:

- ? attain a quantitative and qualitative understanding of the effects of increased temperature on the structure and function of biological communities in streams, lakes and marine waters as well as on sediment mineral cycling
- ? describe coupled effects of nutrients and temperature on the growth and competition of aquatic organisms
- ? transform this information to operational input for ecological impact models and thereby become able to predict the impact of predicted future climate on biological structure and processes (WP 5)

Workpackage 5

Prognoses and simulations of aquatic ecosystems in a climate change perspective

Leader DHI. *Participating institutions:* the entire Consortium

This workpackage will combine the results from the other WPs relating historical, experimental and model simulations to reach a better understanding of possible ecological climate change consequences. The overall intention is to provide examples of cause and effect concerning hydrodynamics in freshwater and marine systems, transport of matter from land to the sea, as well as for key biological and ecological processes in Danish aquatic environments.

The objectives are to:

- produce hindcast and nowcast simulations to describe past and present conditions in different aquatic ecosystems with regard to climate effects
- produce forecast simulations and prognoses for the effect of climate change on different aquatic ecosystems
- assess climate change impacts on a longer time scale in order to identify possible future management strategies and needs

Workpackage 6

A national conference. The ecological consequences of weather and climate changes for freshwater and marine ecosystems: managerial and environmental policy perspectives

Leader: FBL. *Participating institutions:* the entire Consortium

The goal of the programme is to perform ecological analyses that can enable us to identify the influence of climate variability on aquatic ecosystems and thus to provide the possibility of separating the impacts of climate changes and other anthropogenic disturbance. State-of-the-art modelling of regional climate change, hydrology and ecology enables ecological prognoses to be made for different types of aquatic systems. At its most advanced stage, this is where basic science reaches the interface to environmental management and environmental policies.

To conclude the project the objectives are to:

- present and discuss obtained results and their possible consequences at a national conference
- produce a book where the most important results are summarised and made available to a broader audience

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